AST2210 - Lab exercise:
Diffraction and angular resolution

Abstract

In this laboratory exercise you will experimentally study *diffraction*, a basic phenomenon associated with the wave-like nature of light. This phenomenon represents the fundamental limit on the angular resolution for any telescope, and is as such of critical importance in observational astronomy. In the first part of the project, you will first measure diffraction from a single slit, in order to study the nature of the effect in a very well controlled example, before you proceed to study the same for a circular aperature, which more closely mimics a real-life telescope. From the latter, you will estimate the angular diameter of the resulting Airy disc, and you will use this to estimate the angular resolution of JWST. The results will be written up into a report taking the form of a mainstream scientific paper.

1 Diffraction by a single slit

For the following exercises, we will use a simple set-up with a small laser (so not the one with the fiber attached to the collimator tube) and a 100 μm slit. A small laser tube is mounted on a simple platform and powered by a 4.5 Volt flat battery, see Figure 1. First, aim the laser on the slit and project the diffraction pattern on the wall.

WARNING: *The laser beam can damage your eyes if not used correctly. Therefore, use the protective glasses and never look directly into the laser beam or its reflections.*

1. Measure the wavelength of the laser by using the diffraction pattern from the slit and using the formula for single-slit diffraction $a \sin(\theta) = m\lambda$, where a is the slit width, and m the order of the minimum. Calculate the uncertainty of your measurement.

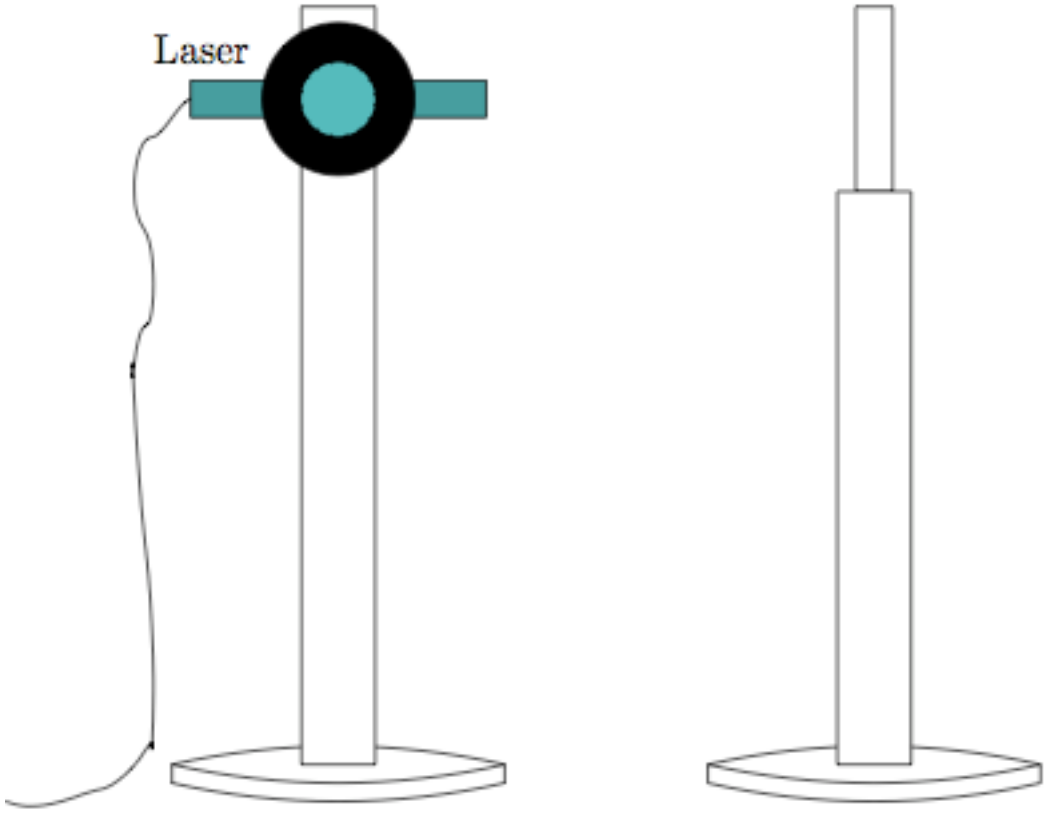

Figure 1: The small laser tube is mounted on a simple platform and powered by a 4.5 Volt flat battery. The 100 μm slit and paperclip are on a separate mount (left).

2. Replace the slit by a bent paperclip. Compare the diffraction patterns of a slit and a “anti”-slit, and use Babinet’s principle to explain what you see.
3. Use the “anti”-slit diffraction pattern to determine the thickness of the paperclip and calculate the uncertainty of your measurement.

2 Diffraction by a circular aperture

Next, we will use a set-up with the laser connected through the fiber to the collimator tube, *with dampening filter*. The (parallel) light from the tube is focussed by an f=100 mm doublet lens. The microscope objective and mono-chromatic camera are used to magnify and image the resulting Airy pattern in the focal plane.

4. Verify that the microscope objective correctly images the focal plane and record an exposure for your report. The angle of the minima is given by the formula $\sin\theta = K\lambda/d$, with d the diameter of the aperture. For the second minimum, the constant is $K = 2.23$. Take an exposure for your report and determine the values for K for the first minimum, and calculate the uncertainty in your measurements. Note that the camera has 6 μm pixels and the microscope objective magnifies $20\times$.
5. Use the circular aperture reducer to reduce the aperture and record exposures at different amounts of reduction. Describe and explain what happens to the Airy pattern.
6. Have a close look at the patterns of dust in the optical system in the image and record an exposure. Describe the pattern and explain.
7. Arago spot. Remove the lens from the set-up (*use gloves*) and replace by a coin (*without central hole*). Remove the microscope objective and the camera. Remove the dampening filter: replace the part of the laser collimator tube with the dampening filter by the corresponding part of the white light tube. Turn on the laser and describe the effect of the circular obscuration in the beam by looking at the pattern on the wall.

3 Scientific report: The angular resolution of JWST

In the above experiment you will have experimentally derived an expression for the effective diameter of the Airy disc on the form

$$\theta_{\text{min}} = K\,\lambda/d. \tag{1}$$

This represents the smallest angular size a telescope with mirror diameter d observing at wavelength λ can observe; that is, a true point-source on the sky is projected into a blob of this angular size. Use this expression to

1. estimate the angular resolution of JWST, given the information that its mirror diameter is 6 meters, and it will observe at frequencies between 600 nm (orange) and 28.5μm (mid-infrared). Report the angular resolution for both wavelength extremes.
2. estimate the smallest physical size of an object that JWST can resolve while observing at various distances. In particular, consider the following cases:
   (a) JWST located in a near-Earth orbit, 540 km above ground, looking at objects on the ground. (Can you think of examples for why somebody would ever want to do that..?)
   (b) JWST located at Earth, looking at small structures on the Sun, at a distance of 1 AU.
   (c) JWST located in the Solar System, looking at the Galactic Center, located at a distance of 8.5 kpc.
   (d) JWST located in the Milky Way, looking at a galaxy forming 4 billion light years away.

Report all numbers with uncertainties, propagating the uncertainty you found in the first part of the project.

The report of the project will be written in the form of a research paper, using a standard LaTex template. The report should contain the recorded images taken throughout the exercises, background to the exercises, comments on the results and explanations of the various optical setups used. Pretend that this is completely new (and Nobel-prize level) work, and you are the first to ever derive the above expressions and results. Use your imagination, and don't be shy! :-)